Matter in Extreme Conditions Instrument (MECi) at LCLS

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MECi Workshop

April 13, 2009

- MECi overview
- MECi x-ray system
- MECi target chamber
- MECi laser system
- MECi baseline diagnostics
MECi proposed for LCLS will cover a wide range of experiments

- **Creating Warm Dense Matter**
  - Generate ~10 eV solid density matter
  - Measure the equation of state

- **Probing dense matter with Thomson Scattering**
  - Perform scattering from solid density plasmas
  - Measure $n_e$, $T_e$, $\langle Z \rangle$, $f(v)$

- **Plasma spectroscopy of Hot Dense Matter**
  - Use high energy laser to create uniform HED plasmas
  - Measure collision rates, redistribution rates, ionization kinetics

- **Probing High Pressure phenomena**
  - Use high energy laser to create steady high pressures
  - Produce shocks *and* shockless high pressure systems
  - Study high pressure matter on time scales < 1 ps
  - Diagnostics: Diffraction, SAXS, Diffuse scattering, Thomson scattering
## Specifications for the experiment reduced to a list

<table>
<thead>
<tr>
<th>Item</th>
<th>Purpose</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam-split-and-delay</td>
<td>Beam splitting 1(^{\text{st}})/1(^{\text{st}}), 1(^{\text{st}})/3(^{\text{rd}}), Delay (1(^{\text{st}}),3(^{\text{rd}}))</td>
<td>1(^{\text{st}}) harmonic in unequal parts, 1(^{\text{st}})/3(^{\text{rd}}) separation: from 10(^2) fs to 1 ns adjustable delay</td>
</tr>
<tr>
<td>Focusing optics</td>
<td>Focusing to 100 (\mu\text{m} - 1 \mu\text{m})</td>
<td>0.1 (\mu\text{rad}) angular stability, 0.5 (\mu\text{rad}) figure error, 5 Å surface roughness</td>
</tr>
<tr>
<td>Slits/Aperture</td>
<td>Beam definition</td>
<td>1 (\mu\text{m}) accuracy, 1 (\mu\text{m}) repeatability</td>
</tr>
<tr>
<td>Intensity monitor</td>
<td>Measurement of incident intensity</td>
<td>Transmissive (&lt;5% absolute), single pulse, relative accuracy &lt;10(^{-3})</td>
</tr>
<tr>
<td>Differential pumping</td>
<td>Separation of optics vacuum (UHV) from sample vacuum (HV)</td>
<td>Separation between 10(^{-6}) and 10(^{-9}) torr UHV conditions, High pumping speed</td>
</tr>
<tr>
<td>Target chamber</td>
<td>Sample positioning and orientation, verify sample, FEL and optical laser alignment</td>
<td>X-Y-Z movement (1 (\mu\text{m})), 2 rotations (1 mdeg), Optical microscope</td>
</tr>
<tr>
<td>Detectors</td>
<td>Angle-, space-resolved x-ray emission</td>
<td>Soft x-ray (grating) and hard x-ray (crystal) spectrometers, High efficiency, Scanning not necessary</td>
</tr>
<tr>
<td>X-ray streak camera</td>
<td>Time-resolved detection</td>
<td>Time resolution ~100 fs, efficient</td>
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<tr>
<td>X-diffraction detector</td>
<td>X-ray diffraction and small angle scattering</td>
<td>X-ray detector, 1K x 1K</td>
</tr>
<tr>
<td>Intensity monitor</td>
<td>Measurement of transmitted intensity</td>
<td>Transmissive (&lt;5% absolute), Single pulse, relative accuracy &lt;10(^{-3})</td>
</tr>
<tr>
<td>Spectral monitor</td>
<td>Measurement of mean energy, bandwidth, and harmonic content</td>
<td>Single pulse measurement, E/ E ~10(^4)</td>
</tr>
<tr>
<td>Time monitor</td>
<td>Measurement time domain properties</td>
<td>Single pulse measurement</td>
</tr>
<tr>
<td>Spatial monitor</td>
<td>Single pulse measurement</td>
<td>Single pulse measurement</td>
</tr>
</tbody>
</table>
MECi Layout

Si substrate
50 nm of SiC (90% solid density)

3rd Harmonic
LCLS Far Experimental Hall Layout
MECi Hutch Layout
MECi hutch layout details

(plan view)

X-ray Optics  Target Chamber
MECi hutch layout details
(elevation view)
MECi X-ray Optics

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Device</th>
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<tbody>
<tr>
<td>Tailor X-ray spatial profile ( &gt; 50 microns)</td>
<td>X-ray Slits</td>
</tr>
<tr>
<td>Tailor X-ray spatial profile ( &lt; 50 microns )</td>
<td>X-ray Focusing Lenses</td>
</tr>
<tr>
<td>Tailor X-ray intensity and spectrum</td>
<td>Attenuators</td>
</tr>
<tr>
<td>Tailor X-ray repetition rate</td>
<td>Pulse Picker</td>
</tr>
<tr>
<td>Tailor X-ray spectrum</td>
<td>Harmonic Rejection Mirrors</td>
</tr>
<tr>
<td>Characterize X-ray pulse intensity</td>
<td>Intensity Monitor</td>
</tr>
<tr>
<td>Characterize X-ray spatial profile</td>
<td>Profile Monitor</td>
</tr>
</tbody>
</table>
Pop-in profile monitor

Task: Characterize spatial profile
Diagnostic: Profile-intensity monitor
Goals: 4 micron spatial resolution (1 mm FOV)
50 micron spatial resolution (12 mm FOV)
Leave in intensity-position monitor

Task: Non-invasively characterize pulse energy and beam position

Diagnostic: Intensity-position monitor

Goals: Transmission > 95%

< 0.1% relative accuracy (pulse energy)

< 10 micron relative accuracy (position)
Be lens focusing system

Task: Tailor x-ray spatial profile
Diagnostic: X-ray focusing lenses
Goals: < 2 micron position repeatability (X & Y)
Accommodate 3 lens stacks
Si beam attenuators

Task: Tailor x-ray spatial profile
Diagnostic: Attenuators
Goals: > 2 steps be decade attenuation > 5 keV
> $10^{12}$ attenuation @ 8 keV, $10^4$ @ 25 keV
Minimize wavefront distortion
Pulse picker

Task: Tailor pulse repetition rate
Diagnostic: Pulse picker
Goals: Isolate single pulse from 120 Hz train
        Operate up to 10 Hz
Target Chamber
MECi Target Chamber Concept

Titan Target Chamber - LLNL
Chamber with diagnostics
LLNL Titan Chamber
‘hollow’ legs

Optical bread board legs ‘rest’ on the floor
Laser systems
4x30 J, 532nm ns laser

- Continuum Agilite laser
  - Adjustable width and shape

Split and Relay Imaging

2x25mm glass heads with birefringence compensation

2x50mm glass heads with birefringence compensation

2x50mm glass heads with birefringence compensation

Phase Plate

Double

Phase Plate
160TW, 35 fs laser

Commercial 4 mJ system like NEH or LDRD laser from Spectra or Coherent

Commercial 1.5J QS Nd:YAG Quanta Ray or Continuum

SLAC built Ti:sapphire amplifier

One arm (30J green) From Long pulse laser

SLAC built Ti:sapphire amplifier

Vacuum Compressor with larger gratings for upgrade to 100TW

Vacuum Compressor chamber capable of handling larger gratings for upgrade to 100TW

NOT IN BASELINE
Helen Laser

Continuum Agilite laser
Adjustable width and shape

Beam conditioning

Helen 4-pass amplifier

Transport

Doubler

PhasePlate
Target Diagnostics: examples
Thomson Scattering: two spectrometers measure collective and non-collective scattering

Requirements:
- Two ports
- Two spectrometers
- HOPG ZYA curved, ZYA flat
- Two detectors
- Two different scattering angles $\theta$
- Shielding
- Distance $12 \text{ cm} < F < 30 \text{ cm}$
- Bragg angle $20^\circ < \theta < 60^\circ$
- Filtering (Be, Al, Ti)

<table>
<thead>
<tr>
<th>Spectrometer setting</th>
<th>Curved crystal</th>
<th>Flat crystal ($F&gt;100 \text{ mm}$)</th>
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</thead>
<tbody>
<tr>
<td>Cl K [2.6 keV] (1st order)</td>
<td>$F = 182 \text{ mm}$ (7.2 eV/mm)</td>
<td>$F = 200 \text{ mm}$ (6.6 eV/mm)</td>
</tr>
<tr>
<td>Ti K [4.5 keV] (2nd order)</td>
<td>$F = 140 \text{ mm}$ (11.2 eV/mm)</td>
<td>$F = 200 \text{ mm}$ (7.8 eV/mm)</td>
</tr>
<tr>
<td>Cu K [8 keV] (2nd order)</td>
<td>$F = 250 \text{ mm}$ (31.1 eV/mm)</td>
<td>$F = 200 \text{ mm}$ (38.8 eV/mm)</td>
</tr>
<tr>
<td>Cu K [8 keV] (3rd order)</td>
<td>$F = 167 \text{ mm}$ (25.3 eV/mm)</td>
<td>$F = 200 \text{ mm}$ (21.1 eV/mm)</td>
</tr>
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</table>
EOS: Standard Fourier Domain Interferometry (FDI)

- Sub-nm resolution of surface motion.
- Few mJ pulse energy
- Time history gathered on shot-to-shot base
- FDI beam is transported through air
- FDI can be applied to front and rear of sample

Michelson interferometer for pulse pair generation (2’x2’ footprint)

• Sub-nm resolution of surface motion.
• Few mJ pulse energy
• Time history gathered on shot-to-shot base
• FDI beam is transported through air
• FDI can be applied to front and rear of sample
MECI Baseline Components

- X-ray transport, x-ray optics (including focusing), x-ray diagnostics
- Laser systems
  - 4 x 30 J Long Pulse
  - 150 mJ Short Pulse
- Target Chamber
- Target diagnostics
  - FDI
  - VISAR
  - Spectrometers – crystal and grating
  - Streak camera
- Data Acquisition and controls
Some MECi Challenges

- Target diagnostics examples
  - Design to match the 1-10 \( \mu \)m x-ray beam size
  - Design of x-ray spectrometers for Thomson scattering
  - Detectors

- X-ray optics/diagnostics pulse by pulse
  - Focusing optics
  - Timing (x-ray – laser)
  - Leave in intensity – profile
  - Focal spot size
Special Thanks to:

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